Freeman and Harnit

The Use of Denatured Alcohol in Internal Combustion Motors

Mechanical Engineering

B. S.

1907

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THE USE OF DENATURED ALCOHOL IN INTERNAL COMBUSTION MOTORS

BY

Perry John Freeman
Joseph Milton Harnit

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN MECHANICAL ENGINEERING

IN THE
COLLEGE OF ENGINEERING
OF THE
UNIVERSITY OF ILLINOIS
PRESENTED JUNE, 1907

UNIVERSITY OF ILLINOIS

June 1, 1907

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

PERRY JOHN FREEMAN and JOSEPH MILTON HARNIT

ENTITLED THE USE OF DENATURED ALCOHOL IN

INTERNAL COMBUSTION MOTORS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Mechanical Engineering

L. P. Breckenridge

HEAD OF DEPARTMENT OF Mechanical Engineering

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THE USE OF DENATURED ALCOHOL IN INTERNAL COMBUSTION MOTORS.

INTRODUCTION.

The increased use of internal combustion motors and the demand for alcohol in the arts has brought to bear a great influence on the enactment of laws permitting the manufacture and sale of alcohol, for industrial purposes, without the payment of any special tax.

The first serious attempt to secure tax free alcohol for useful purposes in the United States was made in 1888, when the Senate adopted an amendment to the Tariff Bill passed by the House, providing for tax free alcohol under certain restrictions. This bill failed to pass, and nothing further was done until 1894 when a tariff act provided for a rebate tax to be paid on alcohol used in the arts, medicinal preparations, etc., under regulations to be prepared by the Secretary of the Treasury, upon the presentation of proof that the alcohol was to be so used. As these regulations were never drafted, the law never went into effect, and was repealed June 3, 1896.

Several foreign countries have had duty free denatured alcohol for many years. England removed the tax on denatured alcohol in 1855, Germany in 1887 and Belgium in 1896, and these countries together with France and Austria have made considerable progress in their use of alcohol in the arts and as fuel for internal combustion motors, within the last few years. Although Germany had duty free alcohol in 1888, its use and manufacture were comparatively small until 1901. In that year the potato

crop showed an overproduction of nearly fifty million pounds, and in desperation at the enormous loss which seemed imminent, the potatoes were turned into alcohol. This so stimulated its use that the following year the government had an industrial exposition at Berlin, devoted exclusively to a demonstration of the fuel, power and lighting qualities of the denatured alcohol. Since then the industry has been an established and rapidly growing one, and it is now used in the manufacture of over 500 different articles besides being used as a fuel. Its use has been so successful in England that, in October 1906, a law was passed permitting a much wider range of uses for denatured alcohol.

After the earnest solicitation of the chemists and manufacturers interested throughout the United States, on June 7, 1906, the following Act of Congress was passed and approved providing for the withdrawal from bond, tax free, of domestic alcohol when rendered unfit for use as a beverage or as a liquid medicine, by a mixture of suitable denaturing materials, and thereby removing the internal-revenue tax of $1.10 per proof gallon, or $2.20 per U.S. gallon, 100 per cent pure.

Briefly the law reads as follows:

"On and after January 1, 1907, domestic alcohol may be withdrawn from bond without payment of internal-revenue tax, for use in the arts and industries, and for fuel, light and power, provided said alcohol shall have been mixed in the presence and under the direction of an authorized Government officer, after withdrawal from the distillery warehouse, with methyl alcohol or other denaturing materials suitable to the use for which the

alcohol is withdrawn, but which destroys its character as a beverage and renders it unfit for liquid medicinal purposes; such denaturation to be done upon the application of any registered distillery in denaturing bonded warehouses specially designated or set apart for denaturing purposes only, and under conditions prescribed by the Commissioner of Internal Revenue with the approval of the Secretary of the Treasury. Distillers, manufacturers, dealers, and all other persons handling or using alcohol withdrawn from bond under the provisions of this act shall keep such books and records, execute such bonds and render such returns as the Commissioner of Internal Revenue, with the approval of the Secretary of the Treasury shall require."

The law further provides a maximum fine of $5000.oo and five years imprisonment, together with the confiscation of the personal property and real estate and buildings of any persons attempting to recover or redistil or dispose of any alcohol in violation of this law. (H.R. 17453, Public, No. 201.)

In order to have it difinitely understood that under the new law it is not possible for any farmer or other person to manufacture alcohol without governmental supervision, the following decision is given out by the Commissioner of Internal Revenue:

"There has been no change in the law relating to the manner in which alcohol can be manufactured. Persons who desire to manufacture distilled spirits for any purpose must comply with the law in all provisions relating to the setting up of distilleries and the operation of the same. The usual distiller's bond must be given; the distillery must be surveyed by a duly authorized officer; a storekeeper and gauger must be assigned to duty

at the distillery; and the product must be entered in a distillery warehouse."

Moreover, the still can only be shut down by an internal-revenue officer, thus making it impracticable under existing laws to operate a small still in a desultory manner.

The new law simply provides that the alcohol may be withdrawn free of tax, provided it is denatured so as to be unfit for use as a beverage or in the manufacture of liquid medicinal preparations.

Although as yet the manufacture of alcohol is limited to the regular distilleries, the fact, that in years of overproduction of agricultural products, they may be turned into alcohol and stored for any length of time, will no doubt prove to be one of great economic importance.

It is an assured fact that with the rapid increase in the use of internal combustion motors that some other fuel than that of petroleum products must be found in the future, if the progress is to be unretarded. Gasoline is a by-product of the petroleum that has a paraffine base, and the utmost amount of gasoline that can be extracted from such petroleum is about two percent. Those Texas and western oils having an asphalt base do not yield gasoline.

Alcohol is a fuel which seems to be the best available substitute for petroleum fuels, and since itis made from agricultural products, the supply is practically unlimited. Since it has been used for several years in German built engines, it is an established fact that it can be used successfully as a fuel for

internal combustion motors. Until recently there has been but a very limited number of tests made upon American built engines, and it was the purpose of the writers in taking up this subject to determine the action of alcohol in an American engine and the effect of making simple changes in the construction and operation of a gasoline engine when using alcohol as a fuel.

DENATURED ALCOHOL DEFINED and REGULATIONS.

The term "industrial" or "denatured" alcohol is used to distinguish the alcohol used for technical purposes and in the arts, from that used for beverages or medicinal purposes. Mr. H. W. Wiley, Chief of the U.S. Bureau of Chemistry, in his bulletin No. 268 on "Industrial Alcohol", defines denaturing as follows:

"The process of rendering alcohol unsuitable for drinking is called 'denaturing' and consists, essentially, in adding to the alcohol a substance soluble therein of a bad taste or odor, or both, of an intensity which would render it impossible or impracticable to use the mixture as a drink."

For some purposes, such as fuel for internal combustion motors, the kind of denaturant used is not of prime importance, and for these purposes such agents are used as will form what is termed "completely denatured alcohol". As the agents usually adopted for use in complete denaturation render the alcohol denatured unfit for use in many industries in which ethyl alcohol, if tax free, can be profitably employed, the Government will authorize special denaturants to be used when absolutely necessary.

In the use and handling of incomplete or specially denatured alcohol, the strictest surveillance is exercised. A manufacturer

desiring to use specially denatured alcohol is required to have a special permit and give a bond equal in amount to the tax on the total estimated quantity of alcohol that he will consume during the year which the bond is intended to cover. A special store room must be provided and all conditions approved by the proper officer before the manufacturer is permitted to use the alcohol.

The regulation regarding the use of completely denatured alcohol is not so stringent, and no manufacturer's transportation and storage bond is required. Manufacturers using less than 50 gallons of completely denatured alcohol per month are not required to secure a permit from the collector, keep records or make returns showing the amount of alcohol received and used. Those who use as much as 50 gallons per month must secure a permit before beginning operations, and must purchase the alcohol in the original stamped package and keep it in a locked room until used.

The "Regulations and Instructions Concerning Denatured Alcohol", published September 29, 1906, by the Commissioner of Internal Revenue do not distinguish between a manufacturer who uses alcohol in the actual processes and one who uses it for fuel, but it seems certain that the regulations apply equally well to both.

Persons using alcohol engines must bear in mind that the storing of denatured alcohol in the following places is forbidden. "On the premises of dealers in wines, fermented liquors, or distilled spirits, rectifiers of spirits, manufacturers of and dealers in beverages of any kind, manufacturers of liquid

medicinal preparations, manufacturers of vinegar by vaporising process, or others whose business requires them to keep stored upon their premises, wines, liquors or other beverages. Provided, that druggists are exempt from above provisions."

Persons who desire to engage in the wholesale or retail of completely denatured alcohol, must first secure separate permits to do so. A wholesale dealer may sell in quantities of five gallons or more and then in the original stamped package. The retailers may sell only in quantities less than five gallons and both must keep complete records of all transactions.

Upon the head of each package must be in red letters the words "Denatured Alcohol". A special stamp must also be affixed giving the time and place of denaturing. These stamps must be destroyed by the manufacturer or dealer as soon as the package is empty, and all marks obliterated, and until such is done, the package must not be refilled.

METHODS OF DENATURING.

The general method to be employed for complete denaturing in the United States is as follows:

"To every one hundred parts by volume of ethyl alcohol of desired proof, there shall be added ten parts by volume of approved methyl alcohol and one-half of one part of approved benzine; for example, to every 100 gallons of ethyl alcohol there shall be added 10 gallons of approved methyl alcohol and 1/2 gallon of approved benzine."

As the use of industrial alcohol is just beginning in this country, there has not been any great number of special denatur-

ants adopted, but any proposed method will be passed upon by the Internal Revenue Commissioner.

France and Germany have had several years experience in the use of industrial alcohol, and the following is a partial list of the denaturants used in those countries as given by the English Industrial Alcohol Committee, 1906.

The general denaturing process in France consists in adding to 90 per cent alcohol 10 percent of methyl alcohol, which contains 25 per cent acetone and 2.5 per cent of various impurities. If the product is to be used for lighting or heating 0.5 per cent of heavy benzine is added to the general denaturing agent. As an example of special denaturants which are used in certain cases we may take that where the alcohol is to be used in making chloroform. The ethyl alcohol is denatured by mixing with chloride of lime in solution, and chloral, for which purpose a current of chlorine gas is passed through the alcohol.

The general denaturing agent authorized in Germany consists of 1 part pyridin and 4 parts wood or methyl alcohol to which may be added to each quart approximately 1.7 of lavender oil or rosemary oil. In other words the German denatured alcohol contains 2 per cent of methyl alcohol and 0.5 per cent pyridin, with optionally 0.125 per cent of lavender or rosemary oil.

For use in internal combustion motors alcohol is completely denatured by the use of 1.33 quarts of the general denaturing agent, 0.26 quart of a solution of methly dye, and 2.11 to 21.13 quarts of benzol to every 26.4 Gallons of alcohol.

The following are a few typical examples of incomplete denaturants:

For industrial uses of all kinds: 5.28 quarts of methyl alcohol or 0.53 quart of pyridin bases per 26.4 gallons of ethyl alcohol.

For soap making: 2.2 pounds of castor oil and 24.4 cubic inches of soda solution.

For varnishes and polishes: 2.11 quarts of methyl alcohol and 0.53 quart of turpentine.

For various chemical preparations: 2.64 gallons of sulphuric ether, or 1.06 quarts of benzol, or 0.53 quart of turpentine, or 0.026 quart of animal oil.

SOURCES and COST of MANUFACTURING ALCOHOL.

Since the passage of the industrial alcohol bill a considerable number of experiments have been conducted in various places to determine just what is the most inexpensive source and method of obtaining alcohol. So long as the alcohol was desired as a drink it was necessary that it should be made from special fruits and grains, but since for industrial purposes the taste is of no consequence, anything may be used which contains the proper elements for producing alcohol.

Corn:---The crop which is at present almost the exclusive source of alcohol is Indian corn. It is shown in a report made by Mr. Wiley in a bulletin on the "Sources and Manufacture of Alcohol", that the amount of fermentable matter in corn, which may be converted into alcohol, equals nearly 70 per cent of the total weight of the corn. Thus if a bushel of corn weighs 56 pounds, the total weight of fermentable matter is, in round numbers, 39 pounds. The weight of alcohol that may be produced from any given crop is estimated at a little less than one-half

of the amount of fermentable matter, and for corn this would be about 19 pounds. Since the weight of one gallon of 95 per cent pure alcohol is about 7 pounds, one bushel of corn will produce on the average 2.7 gallons of alcohol. Placing the value of corn used at 40 cents per bushel, the cost of raw material for one gallon of 95 per cent alcohol is 15 cents. If to this we add the cost of manufacture and the dealers' profits, Mr. Wiley places the selling price to the consumer at about 40 cents per gallon.

Barley:---Another important alcohol producing cereal is barley, but it is at present used exclusively for the manufacture of beverages, and is entirely too expensive a source for industrial alcohol.

Rye, Wheat, Spelt, etc;___Rye contains about the same amount of fermentable matter as corn, but it is not used to any extent in this or any other countries for the manufacture of industrial alcohol oweing to the relatively small production and high price. Wheat and the other cereals are not used in this country to any appreciable extent in the manufacture of industrial alcohol, though spelt might become a profitable source of alcohol in some localities.

Rice:---Rice is not used for making alcohol in this country but is used extensively in Japan and some other countries, and has the largest percentage of fermentable matter of all the cereals. If a bushel of unhulled rice costs 92 cents and yields 34 pounds of fermentable matter, the raw material for one gallon of alcohol from this source will cost about 38 cents.

Potatoes:---Government reports show an average yield for potatoes per acre to be less than 100 bushels. The amount of

alcohol which can be obtained from a bushel of potatoes is about 3.6 quarts, and taking the average price per bushel at 61 cents, the cost for raw material to make one gallon of alcohol is 55 cents. It seems highly probable that our American Experiment Stations will produce potatoes similar to those grown in Germany which are too coarse for food, but give a much larger per cent of alcohol per bushel as well as a greater yield per acre. Consular Report, No. 2654 shows that for German grown potatoes, cultivated especially for the manufacture of alcohol, the yield per acre varies from 284 to 428 bushels.

It will be seen, however, that to compete with corn for the manufacture of industrial alcohol, potatoes must be produced at a cost not to exceed 15 cents per bushel. The average amount of fermentable matter in sweet potatoes is somewhat greater than that for the comman variety, but the average yield is about the same, and we may not expect the sweet potatoes to be a strong rival of corn in the production of industrial alcohol.

Other Root Crops, etc. :---Many different things may be profitably grown and used to produce industrial alcohol. A few of these which are used in various countries are, bananas, artichokes, arrowroots, cassava, carrots, turnips, rutabagas, etc. In western states cactus plants have been found to be a source of considerable alcohol and some experiments have been made toward the utalization of these desert products.

It will be seen from the foregoing that for the present the price of alcohol in this country must of necessity be rather high if made entirely of fresh products. There are, however, many industries which have by-products which are now wasted and

which may, perhaps, be converted into a large amount of cheap alcohol.

Corn Stalks, Cane, etc.:---In a speech before the Committee of Ways and Means of the House of Representatives, Secretary of Agriculture, Wilson made the statement that it seems safe to assume that the amount of sugar and starch which goes to waste in the corn stalks every year would produce 100 gallons of commercial alcohol per acre, or from the whole cultivated area devoted to corn production an aggregate of 100,000,000 gallons might be obtained. The stalks of sweet corn, especially, have a large percentage of fermentable matter, and since the corn is plucked early for canning, this might readily be utilized. Of course, under present prices of the competing fuels it is not feasible to utilize this part of the corn crop for the manufacture of alcohol, but our coal mines and petroleum deposits are fixed quantities, and are rapidly being used up, and it is a matter of no small significance that in the somewhat distant future when other fuels are scarce, the stalks of sweet corn, field corn, and sorghum will be available to produce an inexhaustible supply of light and power.

Waste Products from Canneries, etc.:---The waste from apple, grapes and other fruits in the preparation for canning is estimated by Mr. Wiley to be 25 per cent of the total weight. Of this about 5 per cent is fermentable matter and may be recovered as alcohol. The cobs of sweet corn are also rich in sugar and starch, and the yield from this source is about 8 per cent of the total weight of the cobs. It will be seen, however, that it would not be profitable to erect distilleries simply for the

utilization of this kind of wastes, but if the distillery is already established it might be profitable to transform this waste into useful alcohol.

Alcohol from Sawdust:---Several patents have been issued covering processes for the manufacture of alcohol from wood pulp and at present a factory is in operation in Mississippi engaged in making alcohol from sawdust. The process used is known as Classen's patent and consists essentially in heating the wood particles in a closed vessel, at a temperature of 250 to 300 deg. F., in the fumes of burning sulphur. It is then washed and treated with lime to neutralize the remaining acid, and yeast added. After fermentation the products are distilled in the same manner as that from corn. The total available alcohol per ton of wood is claimed to be 25 gallons. Since the relative amount of waste wood is about one ton per thousand feet of lumber, it may be possible to use this as a large source of industrial alcohol.

By-products from the Sugar Industry:---One of the chief sources from which we may expect to obtain the cheap alcohol for the near future is that of the sugar industries. Mr. Wiley states that it may be possible to obtain from the beet and cane sugar industries in the United States,as a by-product, an annual yield of about 8,000,000 gallons of cheap industrial alcohol. According to Consular reports alcohol of 90 percent purity is sold in Cuba at 12 to 15 cents per gallon. This is made from the fermentable matter left in the molasses after all the sugar possible has been extracted together with the sweepings and water used in scrubbing etc. which is placed in a cistern and allowed to ferment.

In France the production of denatured alcohol is stimulated by a bounty of five cents a gallon paid to the distiller for permitting the product to be denatured. According to consular reports, industrial alcohol is sold in France and Germany for 13 and 14 cents a gallon, but as the price fluctuates with the daily market it will probably average somewhat higher.

In summing up the present situation in the United States as regards cost and sources of industrial alcohol Mr. Wiley says: "Under present conditions it is not probable that alcohol can be offered on the market at much less than 40 cents per gallon of 95 per cent strength. It is believed, however that, by paying attention to unused sources of raw materials and increased production thereof, with improved methods of manufacture and denaturing, the price can be very much diminished. Of the raw materials which can be utilized for the manufacture of alcohol, Indian corn is by far the most promising source at the present time. The average price of potatoes must be very much decreased before they can come into competition with corn as a source of alcohol. Waste materials of other industries such as relates to fruits and vegetables, may incidentally be utilized for manufacturing purposes, but could not of themselves become independent sources of profitable industrial alcohol."

DEVELOPMENT of the ALCOHOL ENGINE.

The data for the folbwing brief review of the history of the development of the alcohol engine is taken chiefly from the writings of R. E. Mathot and that given by Dr. Charles E. Lucke, who was employed by the U. S. Government to conduct a series of

tests on internal combustion engines, and published in bulletin No. 277, U. S. Department of Agriculture.

The first serious attempt to examine into the possibilities of alcohol as a fuel for internal combustion motors in competition with petroleum seems to have been made by Professor Hartman in 1894 at Leipzig, Germany. The experiments were made on a Grobb kerosene engine having a fuel rate of .935 pounds or 1.1 pints using kerosene, or a thermal efficiency of 13.6 per cent. When operating on alcohol the engine used about twice as much fuel, giving a thermal efficiency of 12.2 per cent, or a little less than with kerosene. Improvements were made and in 1896 a convention was held in Berlin at which tests were made by a dozen firms, proving that a horse power hour for an engine of 5 Horse power capacity would be realized with 1.194 pounds of alcohol. The following year a 6 H.P. Körting engine having a special alcohol vaporizer, invented by Petreano, showed a consumption of 1.21 pounds or 1.4 pints of 86.2 per cent alcohol by weight. This result showed a thermal efficiency of 17.5 per cent, or an advance of nearly 50 per cent over the Grobb engine tested in 1894. Following this improvement there resulted a continual development of the alcohol motor, interest in which was kept up by exhibitions at which prizes were offered by scientific societies. Thus in 1902, ten engines were entered at Mannheim, and in his report on the tests Professor Meyer gave the results obtained from engines of the Otto-Deutz manufacture as follows: Consumption of alcohol per brake horse power hour .805 pounds and that of gasoline .655 pounds per B.H.P. hour. There has been a continual increase in the use of alcohol engines in Germany,

and at present there are more than 2000 in use in that country not counting the automobiles which use that fuel.

Many of these engines are used to furnish power for small tram ways and have given satisfaction. Professor Strecker of Leipzig sent a circular letter to 120 farmers in Germany using alcohol engines of sizes ranging from 6 to 25 horse power, asking among other things the amount of fuel consumption. The replies showed a maximum of 2.35 pints and a maximum of 0.92 pints per B.H.P. hour with an average of 1.22 pints. These alcohol engines had displaced steam engines for farm purposes, and of the 120 farmers, 9 per cent found the alcohol to cost more, 34 per cent found no difference, while 57 per cent found the alcohol to cost less than for steam.

In France there has been much progress in the use of alcohol engines. In 1894 tho engines tested used 1.667 pounds of alcohol per B.H.P. hour. At the Paris convention in 1901, the best results were obtained with a Brouhet engine, 16 H. P., which used 1.246 pounds of pure alcohol per B.H.P. hour, corresponding to a thermal efficiency of 33.9 per cent. At the International Exhibition at Vienna in 1904, tests were made on a Banki engine built by Ganz and Company of Budapest, which showed a fuel consumption of .948 pounds of pure alcohol, per B.H.P. hour. Since 1904 a marked decrease seems to have been shown in the experiments made to improve the efficiency of Alcohol engines.

The results of this development from 1894 to 1904 may be summed up by saying that the thermal efficiency of the motor has been raised from 12.2 per cent to something over 30 per cent in that time. Of course these results are the best obtainable under

the best conditions and on a specially designed alcohol motor and are not to be taken as average performances. They do indicate, that so far as fuel is concerned, a motor might be constructed which would operate on alcohol at a price which might be twice that of gasoline and yet give more power for less money, other things being equal.

The tests made by Dr. Lucke shown that when alcohol is used in a gasoline engine without careful adjustment of the fuel supply, it will require two or three times as much alcohol as gasoline per B.H.P. hour. Under the best adjustment a small engine consumed 1.23 pounds of alcohol too .69 pounds of gasoline per B.H.P. hour.

TESTS of an INTERNAL COMBUSTION ENGINE USING ALCOHOL and GASOLINE as FUEL.

The object of these tests is to determine the economy with which an internal combustion engine may be run when alcohol is used for fuel, and also to find what effect changing the compression has on the economy and working of the engine. The testing of the engine, with gasoline as fuel, was made in order that a comparison between the use of alcohol and of gasoline might be made.

DESCRIPTION of APPARATUS.

The engine used in these experiments was of the standard, vertical, four-cycle type, made by the Root and Van Dervoort Engineering Company, of Moline, Illinois. (Dimensions, ratings, etc. given in table 1.) The governing was affected by the "hit and

miss" method. The increasing of the compression was obtained by means of plates screwed on the piston. The amount of compression was obtained from indicator diagrams.

The fuel was measured by means of a tank, small in diameter, having a glass connected with it in such a manner that the height of the fuel in tho tank could, at any time, be read from an attached scale. This arrangement is well illustrated in Fig.1.

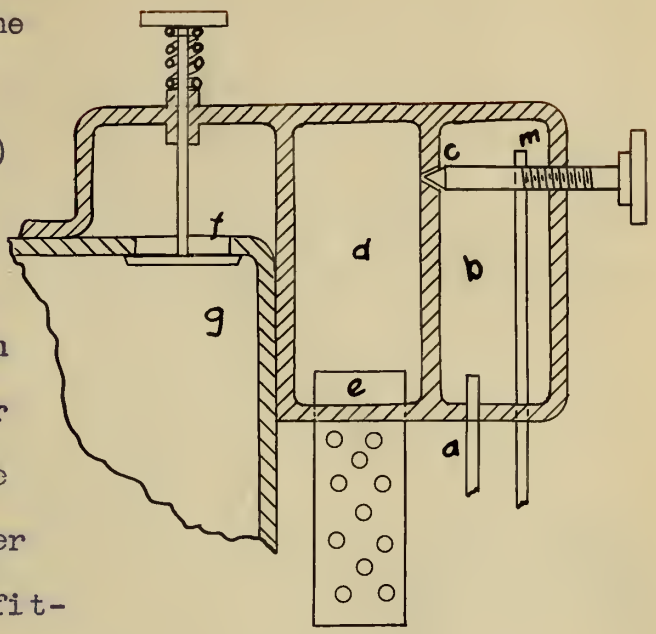
The cylinder walls were kept cool by the usual water jacket. The water was taken from the mains, and after passing through the jacket, emptied into a tank on a set of platform scales where it was weighed. This arrangement is shown in Fig. 2, which also gives a good general view of the engine and testing apparatus.

The brake horse power of the engine was obtained by the use of a prony brake. The style of the brake used is shown in Fig. 3. It consists of a frame, at the bottom of which is fastened a rope. The rope passes around the pulley and into a hook which may be drawn toward the upper part of the frame by means of a hand wheel. It was found that the load could be much more accurately regulated with this type of brake than with one which had an arm of two feet. The arm on this brake was equal to the radius of the brake pulley plus one-half the diameter of the rope.

The same carburetor was used for both alcohol and gasoline. The accompanying sketch shows the principal. By means of a small pump, the fuel from the tank is forced through the pipe (a) into the chamber (b). The flow of the fluid from chamber (b) to chamber (d) is regulated by a needle valve (c).

In this chamber it mixes with the air which comes in through

the perforated cylinder (e), The suction then draws the mixture into the combustion chamber (g) through the valve (f) which is automatically closed when the compression begins. If too much fuel is forced into the chamber (b) it will run out through the overflow pipe (m). On the larger engines it is said to be a profitable investment, when alcohol is used, to have a carburetor such that the exhaust gases may be passed through it, thus keeping it at a higher temperature and causing a better mixture.



METHODS of CONDUCTING the TESTS.

Duration of Runs:---With gasoline there were five runs, each of one hour's duration. During each of these runs, or trials, the load and R.P.M. were kept constant, the load being changed at the end of each trial. With alcohol as a fuel, there were five trials, each of one hour's duration, with each of four different compressions, the load being varied in the same manner, as in gasoline tests. With the most economical compression four trials were made to determine the relation between the speed of the engine and the fuel consumption. In these trials, which were of one hour's duration, the load was kept constant and the R.P.M. varied.

Readings:---Readings were taken at ten minute intervals in all the trials and the averages of each trial are given in the summary of tests (Tables 11 to V11 inclusive).

Speed:---The revolutions per minute were taken with a speed counter, and the number of explosions by means of a speed counter as shown in Fig. 1.

Indicator Cards:---Indicator cards were taken at intervals of ten minutes by a gas engine indicator.

Temperatures:---The only temperature taken was that of the jacket water as it left the jacket. It was taken with a mercurial thermometer graduated from 0 to 220 degrees Fahrenheit.

CHEMICAL ANALYSES.

The following analyses were obtained by taking samples of the fuels and sending them to the Chemistry Department of the University of Illinois.

ALCOHOL.

Specific Gravity at 20 deg. C----------.8175

Total Carbon (determined)----------47.9%

Available Hydrogen(Calculated from B.T.U.----7.13%

Free and Combined Water----------44.97%

Calculated as Ethyl Alcohol from Total Carbon Alcohol----------91.3%

Water---------- 8.2%

B.T.U. per pound----------11401

B.T.U. per gallon----------77732

GASOLINE.

Carbon----------86.8%

Hydrogen (Calculated from B.T.U.)----------12.2%

Oxygen, Nitrogen and Sulphur----------1.0%

Boiling point---70 deg. ---110 deg. C.

Specific Gravity at 20 deg. C.-------- .7264

B.T. U. per pound----------20,214

B. T. U. per gallon ----------123,022

TABLE I.

Data and Dimensions of Engine.

1. Name and Number----------"Zealous" No. B 3484

2 Manufactured by---The Root and Van Dervoort Engineering Company of Moline, Illinois.

3. Type----------Four-cycle.

4. Fuels----------Denatured Alcohol and Crown Gasoline.

5. Heat of Combustion
   - Alcohol--
     - 11401 B.T.U. per lb. or
     - 77732 B.T.U. per gallon.
   - Gasoline--
     - 20,214 B.T.U. per lb.
     - 123,022 B.T.U. per Gallon.

6. Horse power, normal full load----2 B.H.P.

7. Floor space----------24" X 27"

8. Height---------- 3'-6"

9. Weight----------650 lbs.

10. Number of cylinders----------one.

11. Fly wheel diameter----------24"

12. Brake pulley diameter---------- 9"

13. Diameter of piston----------4 3/8"

14. Piston displacement----------.0477 cu. ft.

15. Length of stroke---------- 5 1/2"

16. Revolutions per minute(normal)--335

17. Governor, centrifugal----------"Hit and Miss" method.

18. Kind of ignition---------- Electric spark.

19. Brake arm---------- 4 3/4"

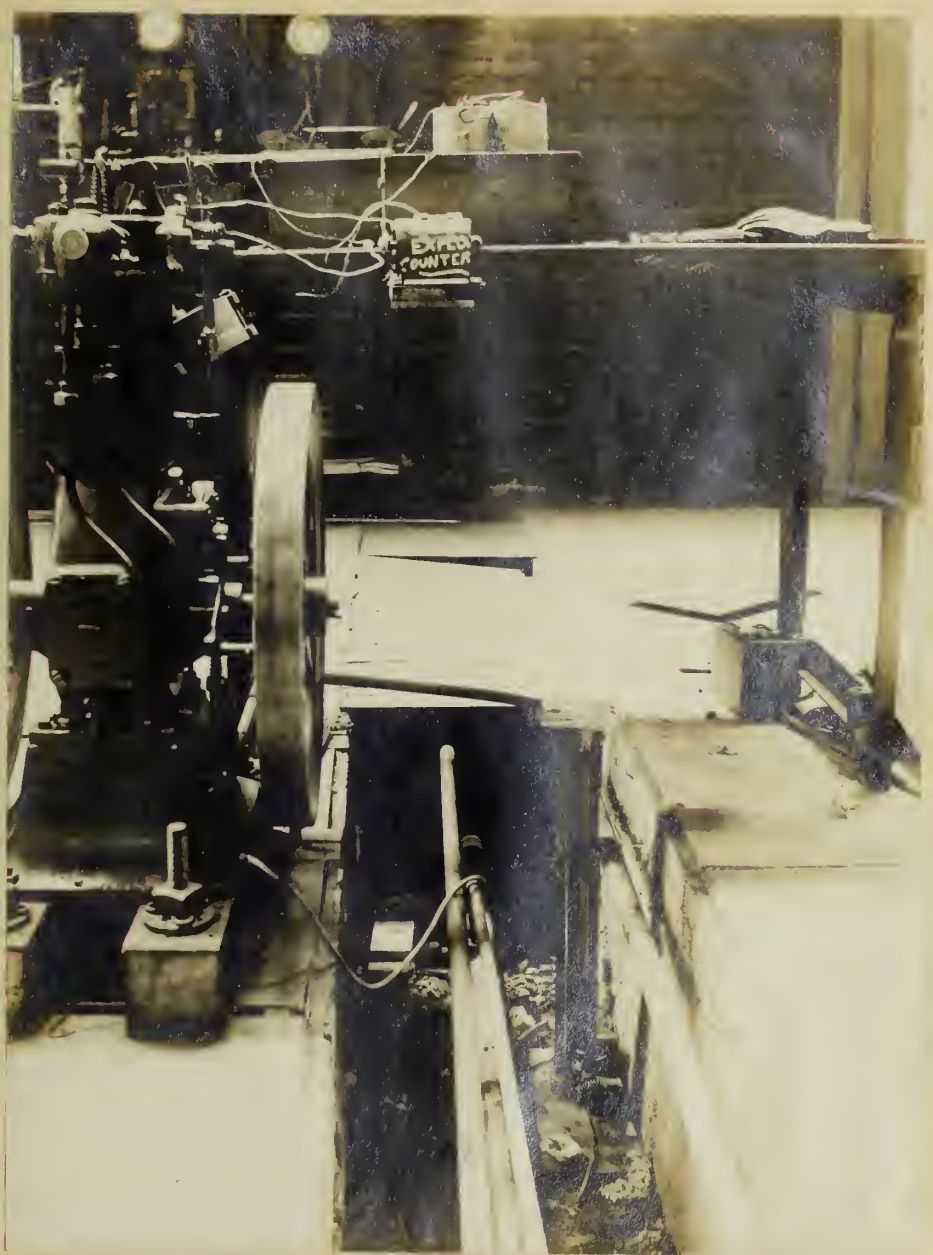


FIG. 1

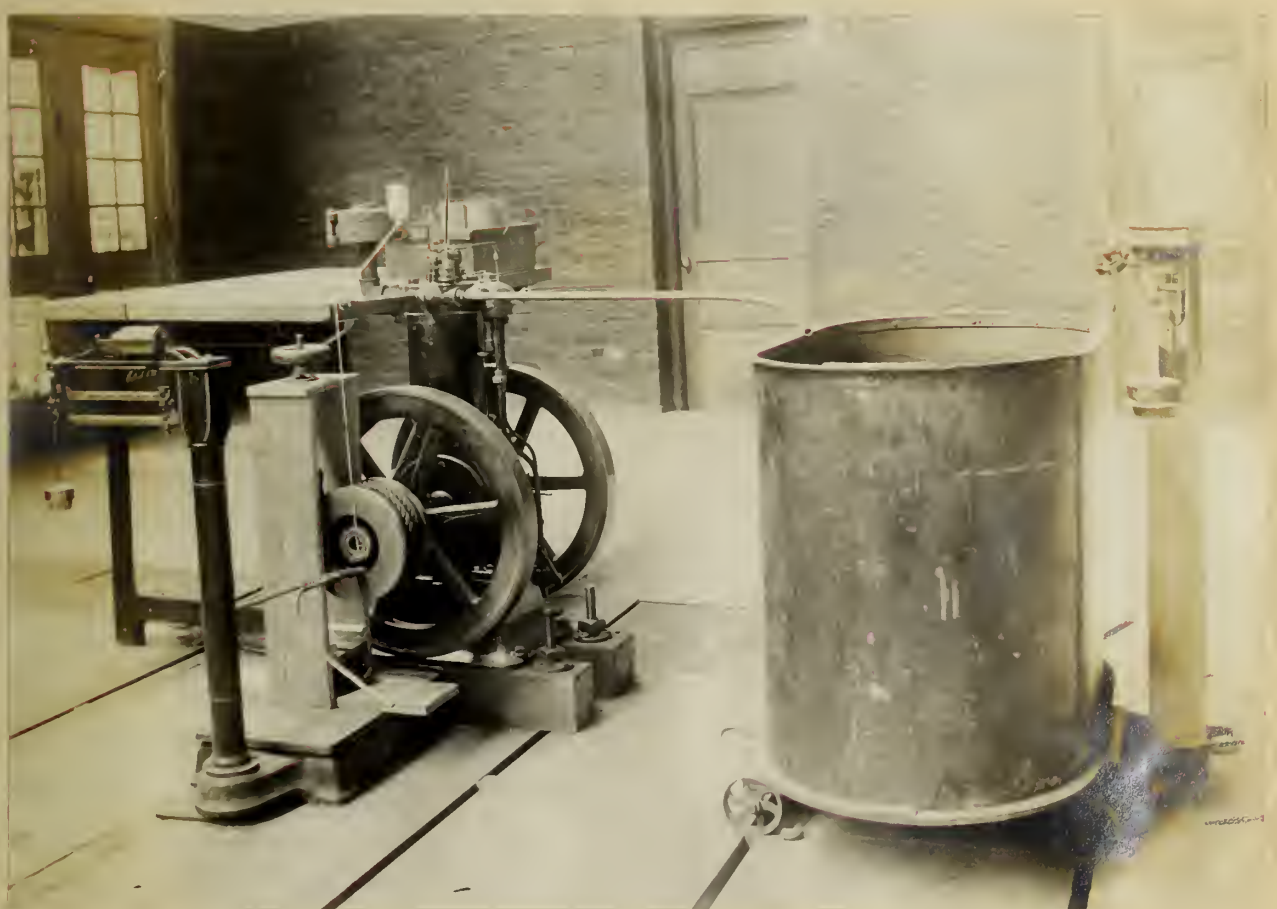


FIG. 2.

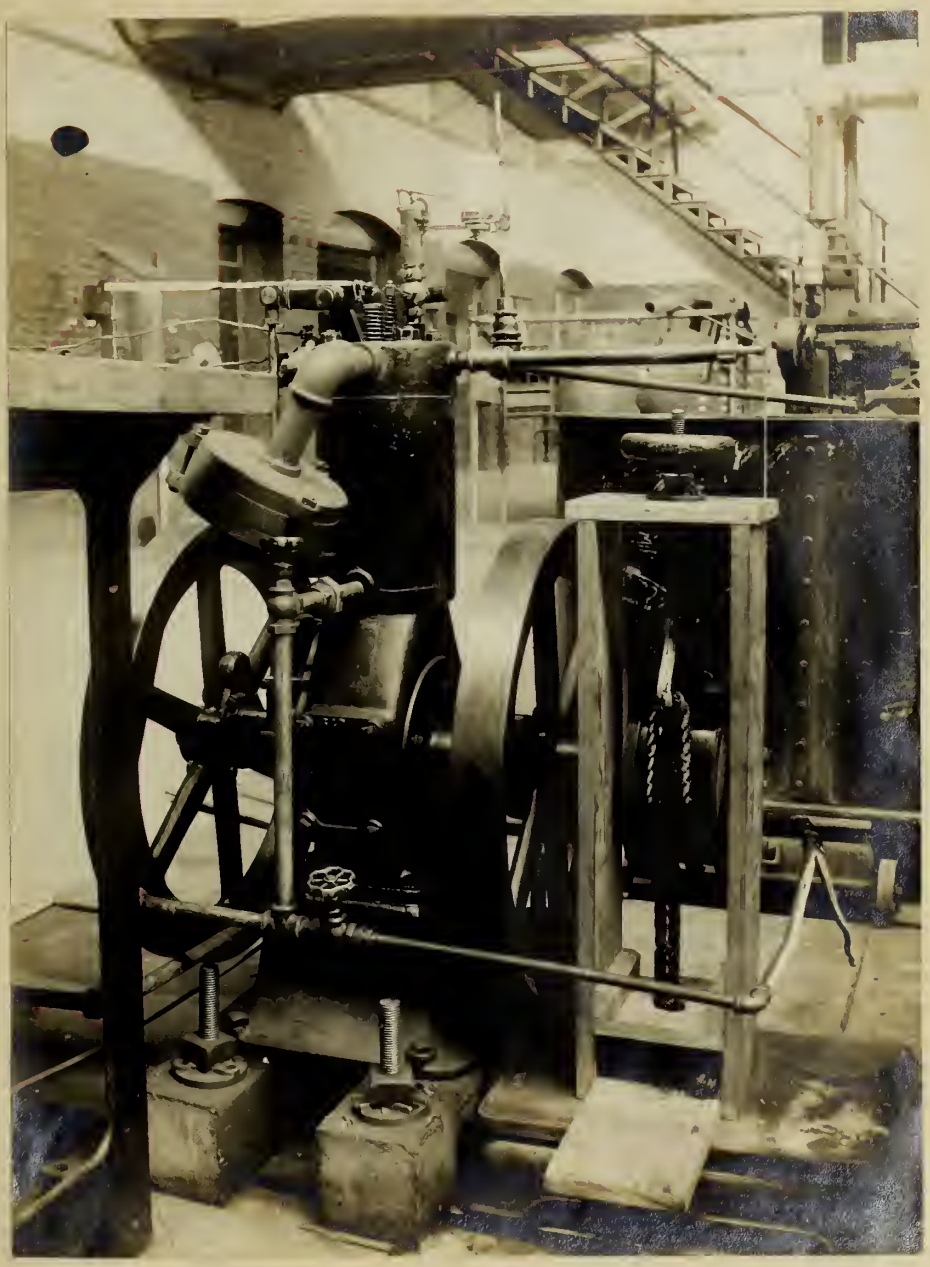


FIG. 3.

METHODS of CALCULATING RESULTS.

The brake borse power was determined by the formula

$$B.H.P. = \frac{2\pi P R N}{33000}$$

in which P = the weight or pull on the arm, R the length of the brake arm, and N the number of revolutions per minute.

The thermal efficiency, which is given in the following tables is based on the brake horse power and the total number of B.T.U's contained in the fuel and is obtained by the following formula:

$$\text{Thermal efficiency} = \frac{B.H.P. \times 33000 \times 60}{n \times H \times 778}$$

where n = number of pints of fuel consumed during a trial of one hour's duration and H = the total number of B.T.U's contained in one pint of the fuel.

The fuel rate per B.H.P. hour was obtained by dividing the number of pints used in a one hour's trial by the B.H.P. developed. All results were thus given on the B.H.P. hour basis.

TABLE II.

Gasoline Test — R.P.M. - 335.
Compression - 88 Lbs. — Temp. of Jacket Water - 139°F

Trial Number	Duration in Minutes	Brake Horse Power	Fuel per B.H.P. Hour. Pints	Thermal Efficiency	Weight of Jacket Water
1	60	.542	1.980	8.35	100 #
2	60	1.060	1.540	10.75	130
3	60	1.580	1.545	10.70	160
4	60	2.075	1.580	10.50	185
5	60	2.495	1.613	10.20	205

TABLE III

Alcohol Test — R.P.M. - 335
Compression - 84 Lbs — Temp. of Jacket Water - 135°F

Trial Number	Duration in Minutes	Brake Horse Power	Fuel per B.H.P. Hour. Pints	Thermal Efficiency	Weight of Jacket Water
1	60	.504	3.42	7.65	90 #
2	60	1.000	2.25	11.60	105
3	60	1.528	1.78	14.70	130
4	60	2.008	1.57	16.70	150
5	60	2.538	1.67	15.70	175

TABLE IV.

Alcohol Test. — R.P.M. - 335
Compression - 110 Lbs. — Temp. of Jacket Water - 137°F.

Trial Number	Duration in Minutes	Brake Horse Power	Fuel per B.H.P. Hour. Pints	Thermal Efficiency	Weight of Jacket Water.
1	60	.515	2.52	10.40	100 #
2	60	1.012	2.21	11.80	115
3	60	1.526	1.84	14.25	140
4	60	2.040	1.77	14.80	165
5	60	2.550	2.03	12.90	180

TABLE V

Alcohol Test. R.P.M. - 335.
Compression - 116 Lbs. Temp. of Jacket Water - 140°F

Trial Number	Duration in Minutes	Brake Horse Power	Fuel per B.H.P. Hour. Pints.	Thermal Efficiency	Weight of Jacket Water.
1	60	.507	2.14	12.2	65 #
2	60	1.023	1.99	13.2	80
3	60	1.518	1.85	14.2	125
4	60	2.044	1.71	15.3	160
5	60	2.480	1.96	13.4	190

TABLE VI

Alcohol Test. R.P.M. - 335.
Compression - 127 Lbs Temp. of Jacket Water - 131°F

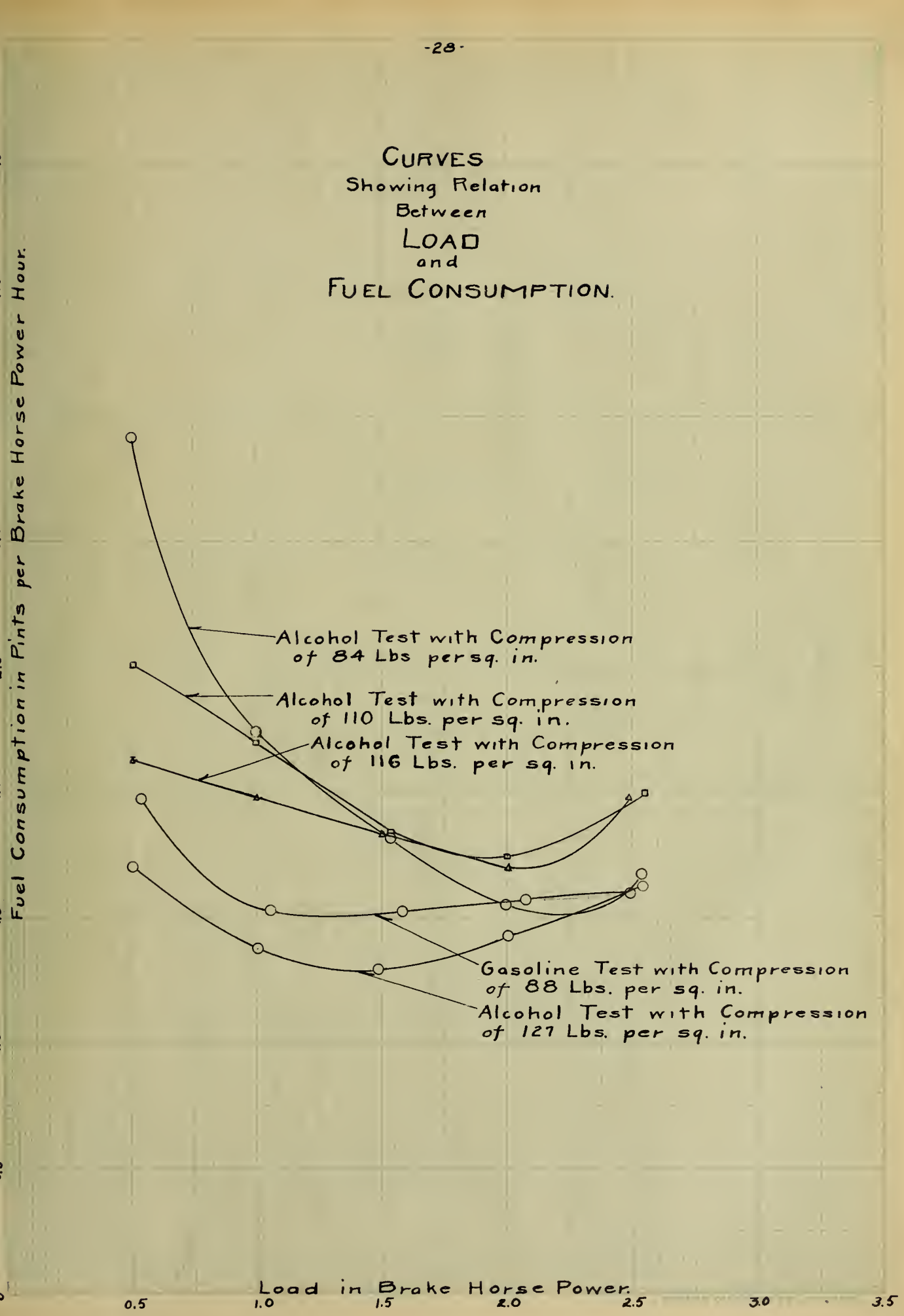
Trial Number	Duration in Minutes	Brake Horse Power.	Fuel per B.H.P. Hour. Pints	Thermal Efficiency	Weight of Jacket Water
1	60	.520	1.710	15.3	110
2	60	1.003	1.390	18.8	134
3	60	1.490	1.310	20.0	150
4	60	2.090	1.435	18.2	180
5	60	2.540	1.640	16.0	215.

TABLE VII

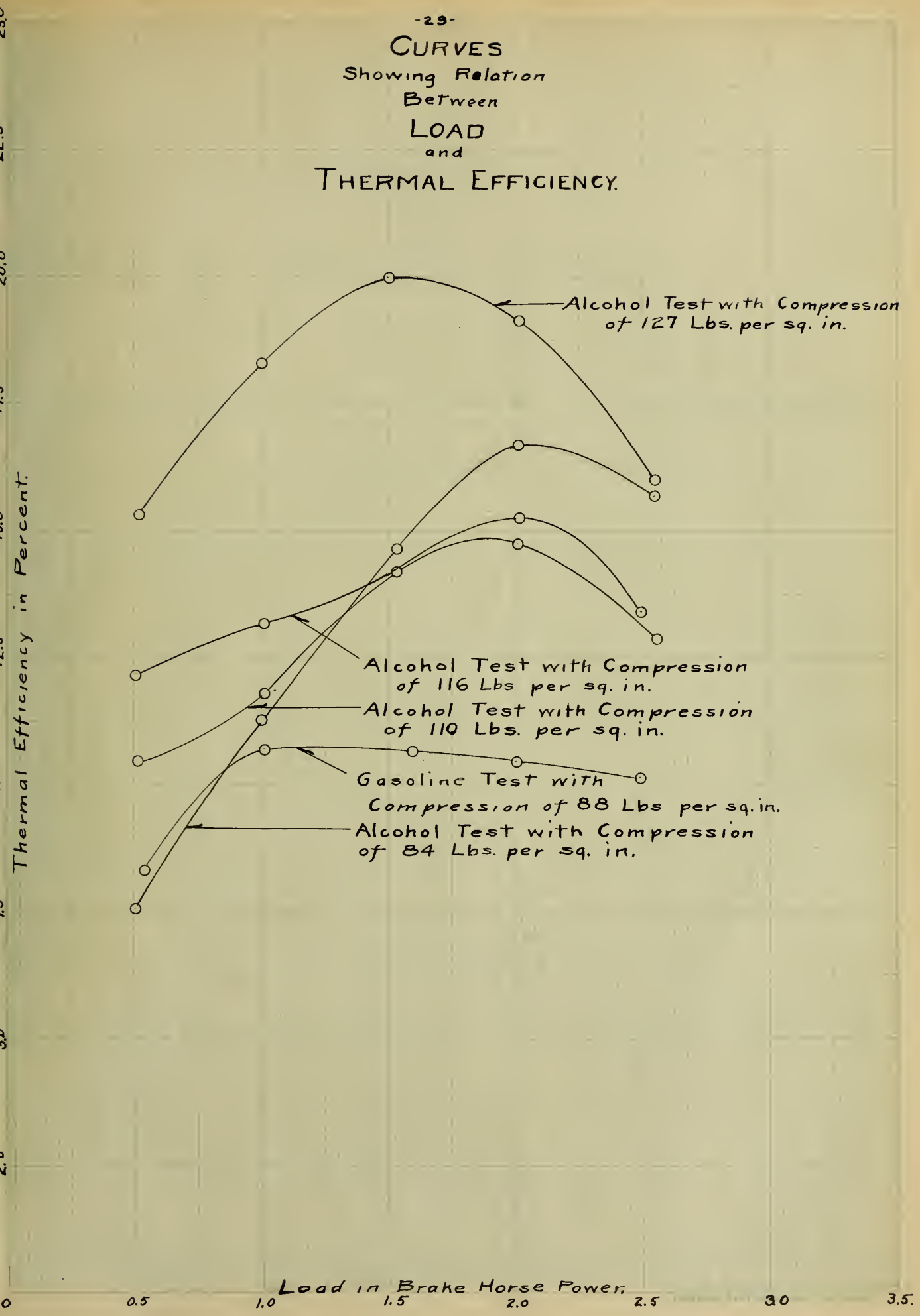
Alcohol Test. Load - 1.5 Brake Horse Power
Compression - 127 Lbs Temp. of Jacket Water - 145°F.

Trial Number	Duration in. Minutes	R.P.M.	Fuel. per B.H.P. Hour. Pints.	Thermal Efficiency	Weight of Jacket Water
1	60	275	2.06	12.9	120 #
2	60	335	1.31	20.0	150
3	60	375	1.50	17.5	145
4	60	450	2.20	11.9	140

CURVES
Showing Relation
Between
LOAD
and
FUEL CONSUMPTION.

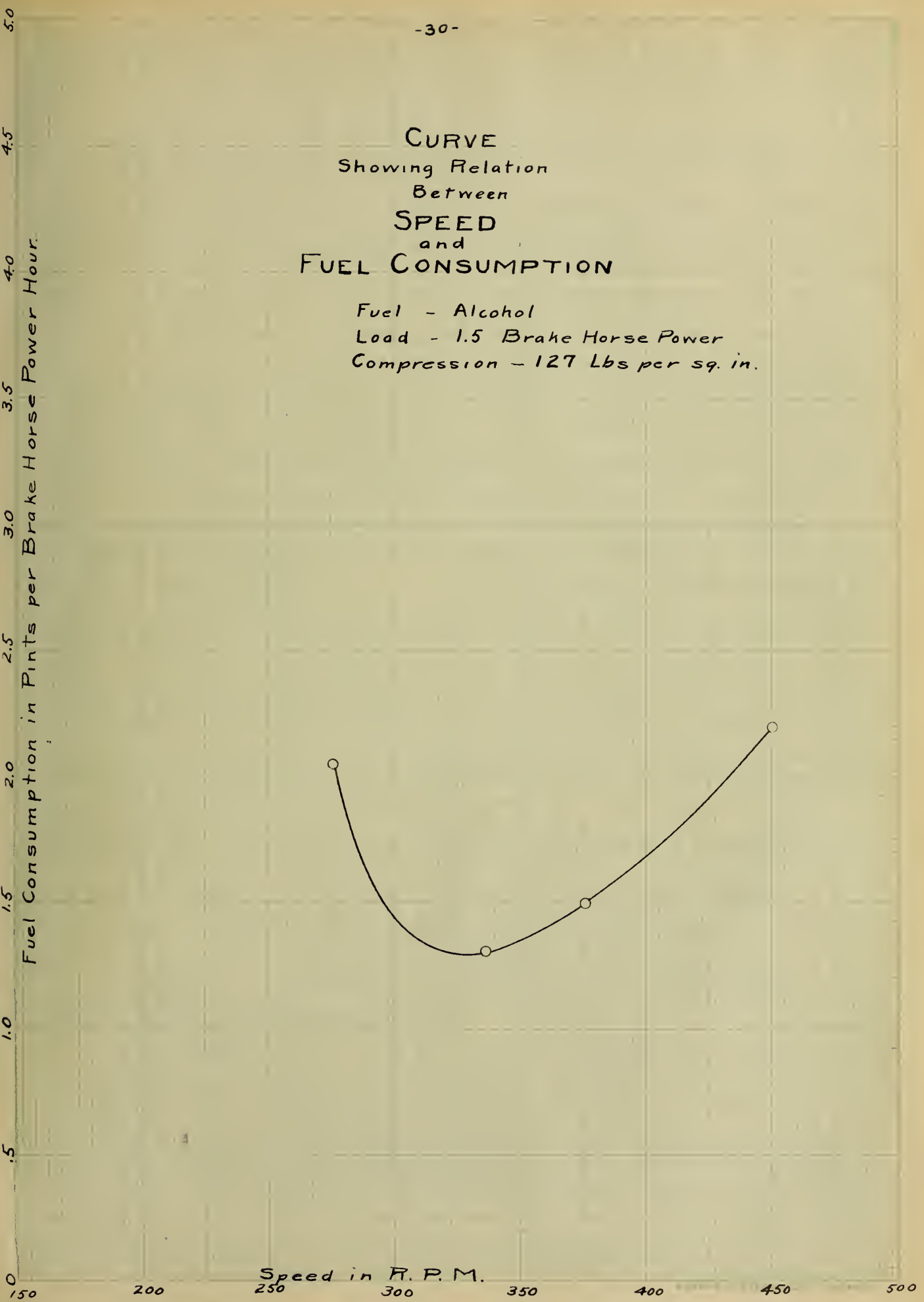


CURVES
Showing Relation
Between
LOAD
and
THERMAL EFFICIENCY.



CURVE
Showing Relation
Between
SPEED
and
FUEL CONSUMPTION

Fuel - Alcohol
Load - 1.5 Brake Horse Power
Compression - 127 Lbs per sq. in.



DISCUSSION of RESULTS.

The manner in which the fuel consumption varied as the B.H.P. was changed, other conditions remaining constant, is shown by the curves of page 28 . The most economic load of the engine, with gasoline as a fuel, lies between one and one and one-half horse power, although there is but very little variation in the fuel rate when the load is increased from one horse power to two and one-half horse power. It can readily be seen from the curves that, with alcohol as a fuel, the greatest economy of the engine was secured when the compression was highest. The best results were obtained while the engine was running on a load of one and one-half horse power and a compression of 127 pounds per square inch. The curves show that, up to a load of one and one-half horse power, the economy increased as the compression increased. For greater loads, no direct law can be given for the variation in economy, but, in general, it can be seen from the curves that economy is made greater as the compression is increased. The variation of the thermal efficiencies are shown by curves on page 29. It can be readily seen that the thermal efficiency in the alcohol tests is much greater than in the gasoline test, the maximum efficiency of the alcohol being almost twice that of the gasoline.

Table VII and the curve on page 30. show that the rate of fuel consumption increased as the speed of the engine is increased above its normal rating. The greatest economy was secured when the engine was running at tis normal rating of 335 R.P.M.

CONCLUSIONS.

The following conclusions, regarding the use of alcohol as fuel for internal combustion engines, are based upon the results of the experiments carried on by the writers and upon the results of such experiments and investigations as have been discussed in the technical journals and governmental bulletines.

(1) Any engine on the American market, operating with gasoline, may, with proper manipulation, be operated with alcohol as a fuel, without any structural change.

(2) That it requires no more skill to operate an engine using alcohol than one using gasoline, except that the engine is a little more difficult to start when a high compression is used.

(3) The thermal efficiency of the engine may be very materially increased by increasing the compression.

(4) That any engine, operating with alcohol as a fuel, will carry a slightly greater load than with gasoline.

(5) That alcohol is very much more pleasant and much less dangerous to handle than is gasoline.

(6) Alcohol dissolves readily in water and when afire may be easily quenched. This is not true with gasoline.

(7) The exhaust from the alcohol engine is not near as hot as that from the gasoline engine, which fact would seem to indicate that there is less danger from fire and less possibility of the burning of the lubricating oil. No smoke is given off in the exhaust if the engine is properly manipulated.

(8) Alcohol acts upon iron, forming a rust. This fact makes it necessary, when the engine is to stand still for any lengthof time, to run into the cylinder a quantity of some alkaline

substance or oil.

(9) An engine may use much more fuel than is necessary and yet seem to be working all right. If gasoline were so used it would smoke.

(10) The experiments of Prof. Elihu Thompson show that alcohol engines will economically operate with as much as twenty per cent of water in the fuel. Above this percent of water, the ignition becomes irregular.

(11) Prof. Lucke says that alcohol by reason of its great safety and its adaptability to the work, should supplant gasoline for use in boats. He also says that in most localities, it is unlikely that alcohol power will be cheaper or as cheap as gasoline power for some time to come.

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